Projectile Impact Evaluation on Ballistic Gelatin

SEM 2011

Duane Cronin [University of Waterloo]
Amal Bouamoul [DRDC Valcartier]

June 13, 2011

Report Documentation Page	*Form Approved OMB No. 0704-0188*

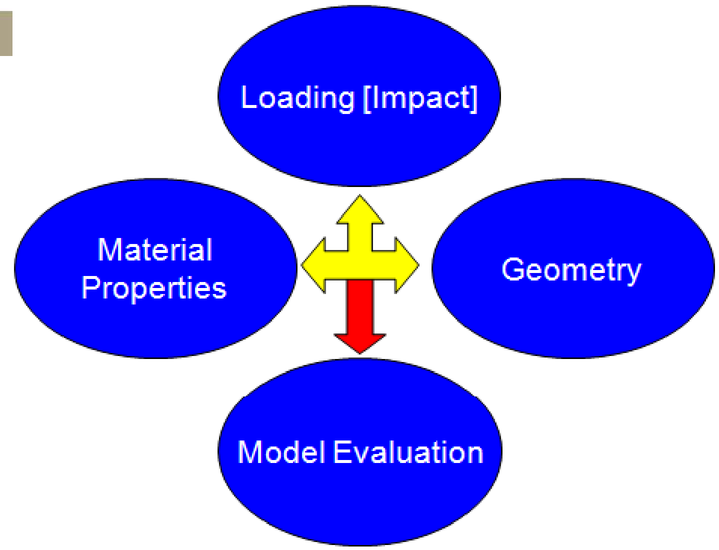
1. REPORT DATE **13 JUN 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**
4. TITLE AND SUBTITLE **Projectile Impact Evaluation on Ballistic Gelatin**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defence R&D Canada - Valcartier,2459 Pie-XI Blvd North,Quebec (Quebec) G3J 1X5 Canada,**		8. PERFORMING ORGANIZATION REPORT NUMBER **; DRDC-VALCARTIER-SL-2011-**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S) **DRDC-VALCARTIER-SL-2011-**
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

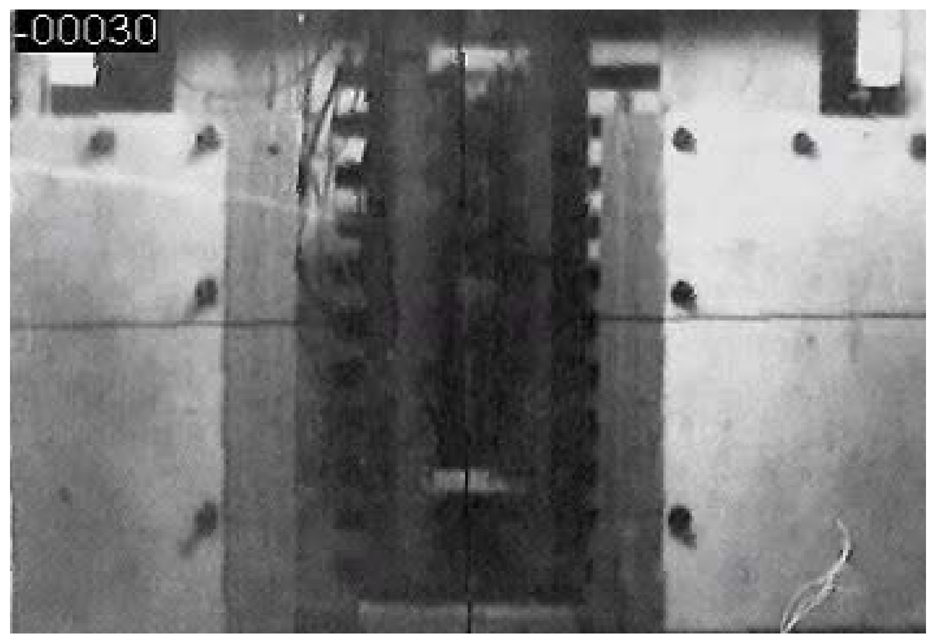
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**15**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

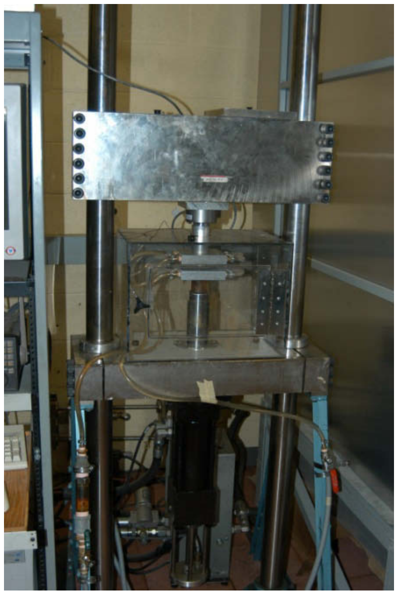
Introduction / Background

- Ballistic gelatin widely used as a tissue simulant (10% and 20%)
- Examples
  - Penetrating trauma (ballistic)
  - Tissue response to blast (lower extremity, torso)
  - Blunt trauma

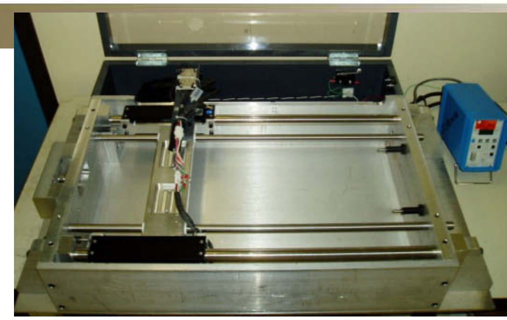


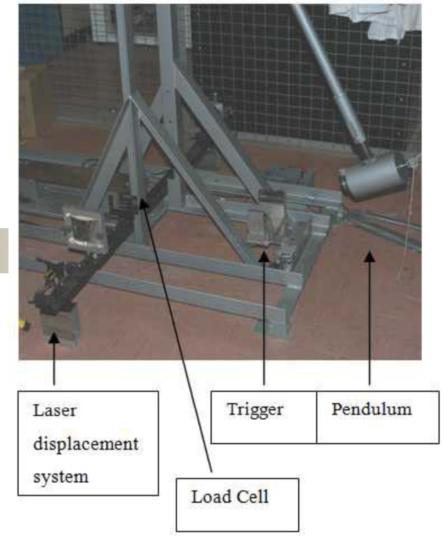


Mechanical Testing

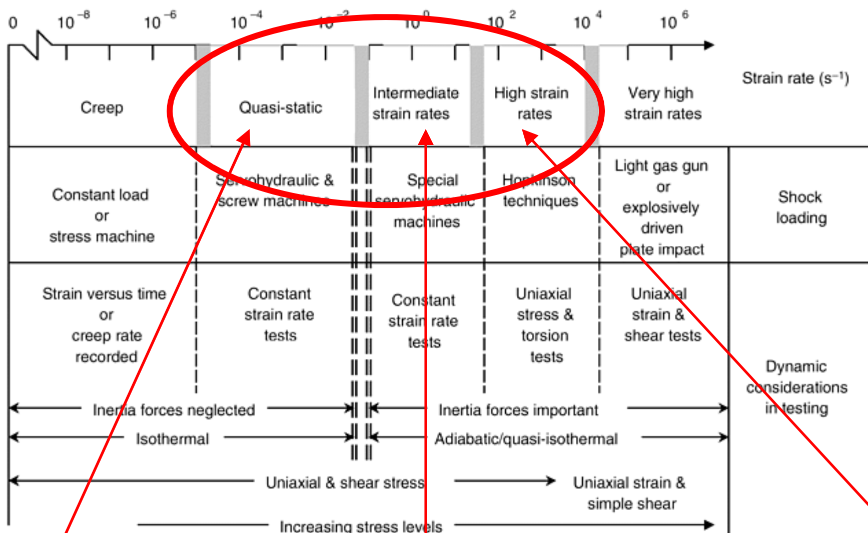


(~0.01-10 1/s)





(~100-500 1/s)



From ASM, Volume 8, Mechanical Testing and Evaluation

(~300-3000 1/s)

Campbell, SEM 2007
Ouellet, Exp Mech 2006
Doman, Exp Mech 2006
VanSligtenhorst, JoB 2006
Ouellet, PASS 2004
Motuz, SAV 2003
VanSligtenhorst, ASME BED 2003
Salisbury, Plasticity 2002

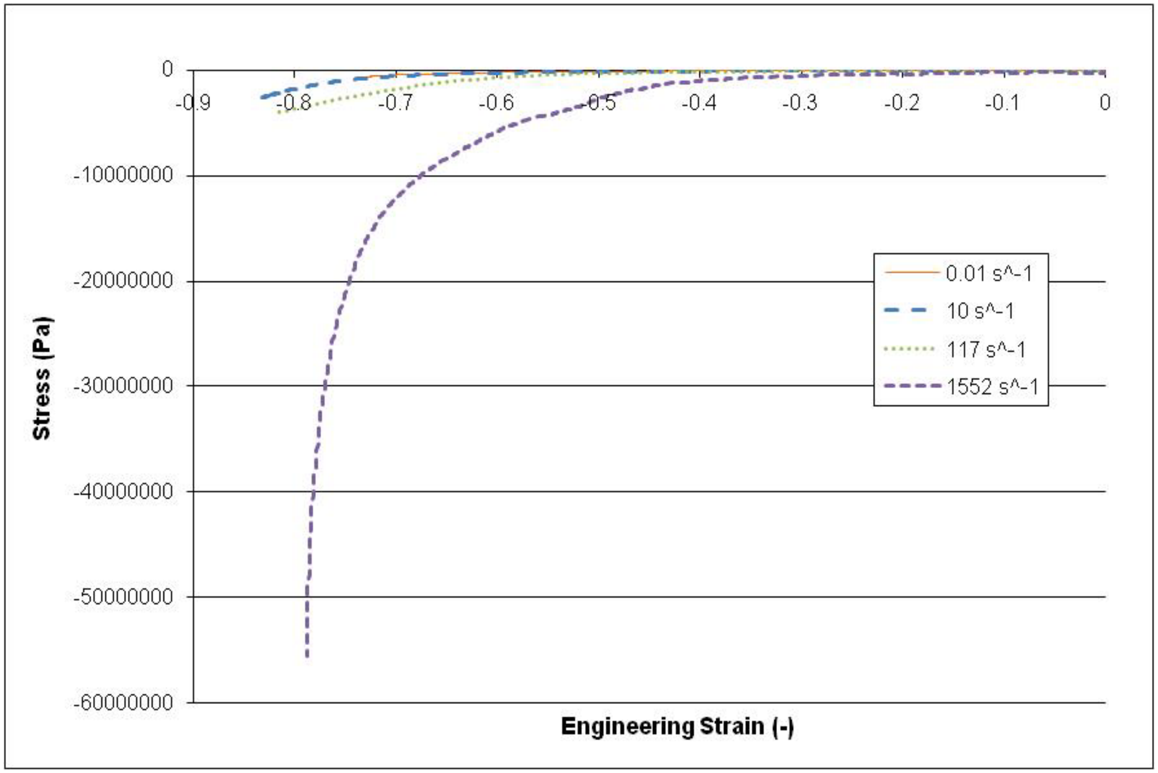
Servohydraulic

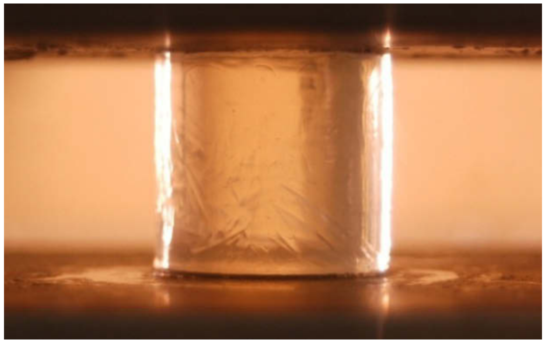
Pendulum Impact
Drop Tower
EM Test Frame

Polymeric Split Hopkinson
Pressure Bar Apparatus

Introduction / Background

- 10% / 4°C mechanical properties
  - similar to those of soft tissue [vanSligtenhorst 2004, Cronin, 2006]
- Hyperelastic model with rate effects [Kolling 2007]
  - Ogden formulation with linear bulk modulus





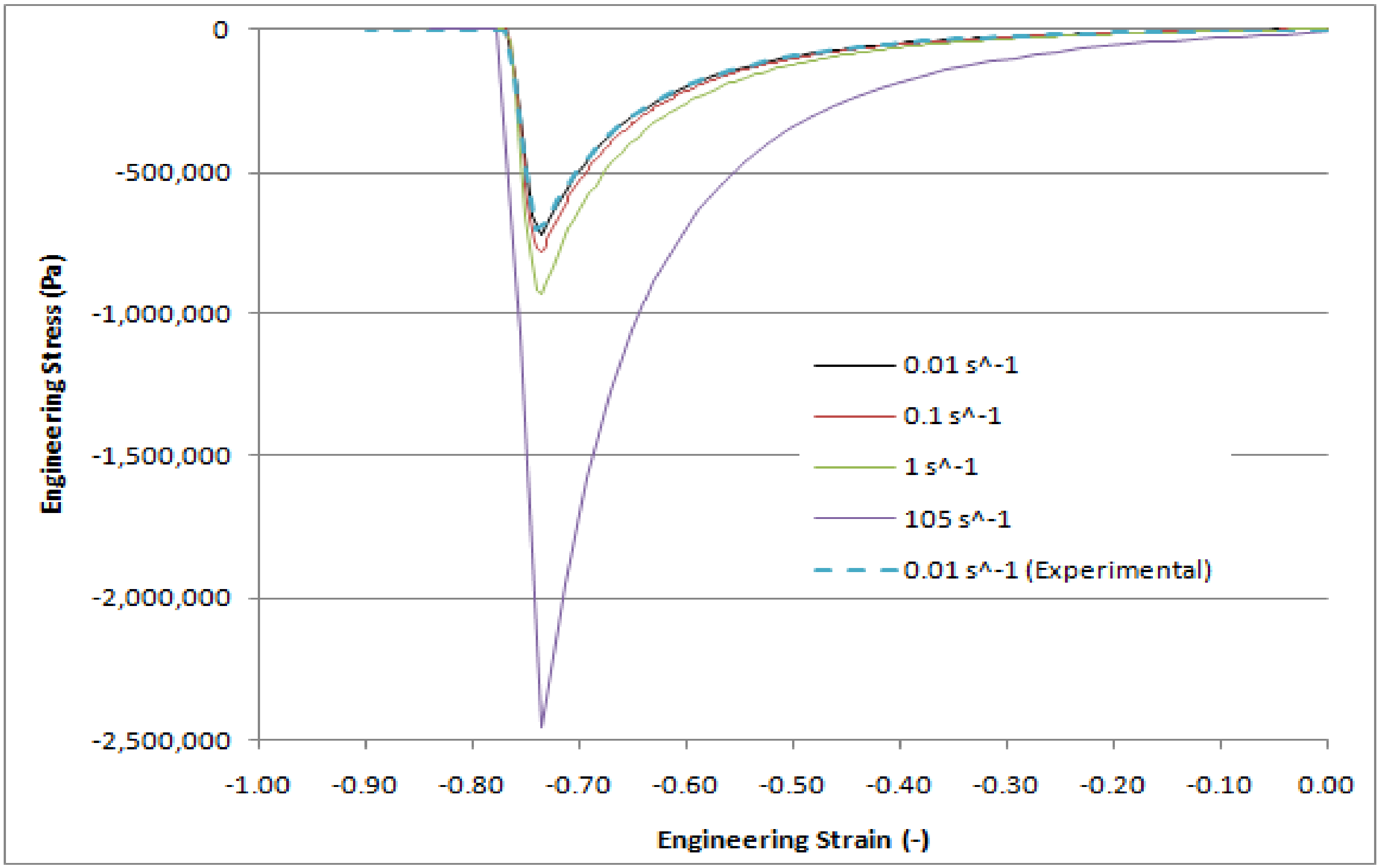
Impact modeling

- Damage model

  [DuBois, Kolling, LSTC]

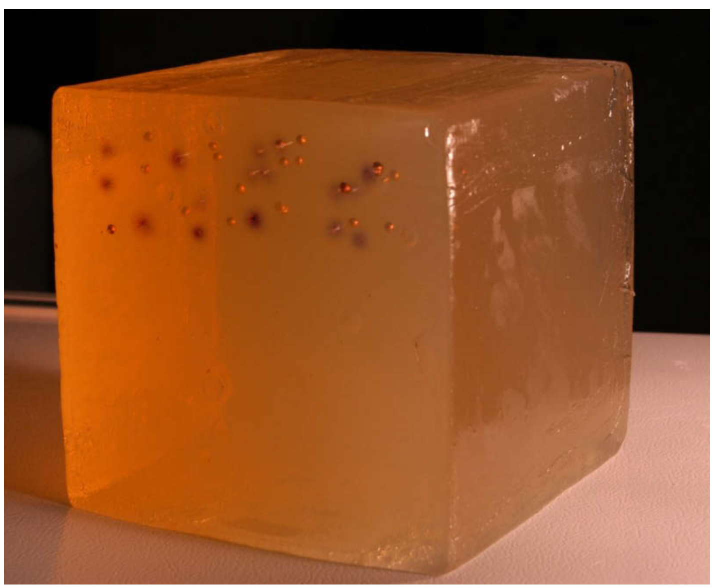
$$f(I_1) = (I_1 - 3)$$

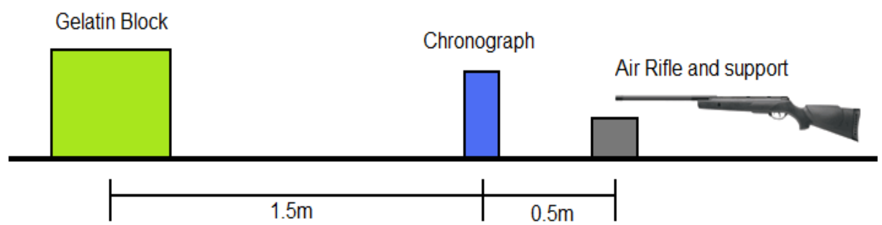
$$D = \begin{cases} 0.0 & f \leq (1-h)K \\ \frac{1}{2}\left[1 + cos\left(\frac{\pi(f-K)}{hK}\right)\right] & (1-h)K < f < K \\ 1.0 & f \geq K \end{cases}$$

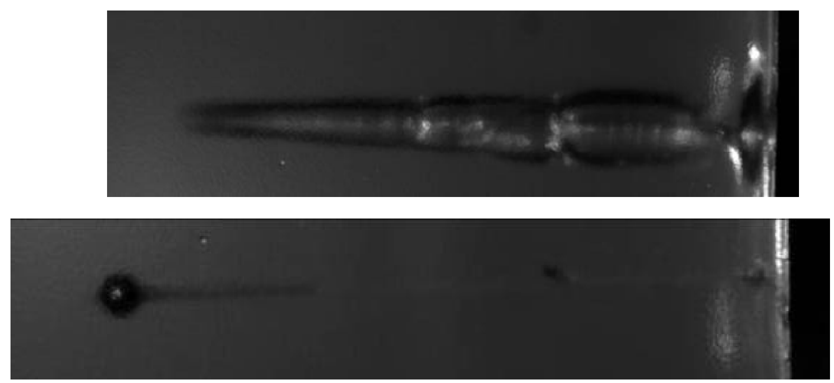


Methods – Gelatin Calibration

- Calibration (10%/4°C)
  - Impact at various velocities using a 4.35 mm diameter (0.35 gram) BB on a 250mm x 200mm x 200mm block (Jussila 2004)

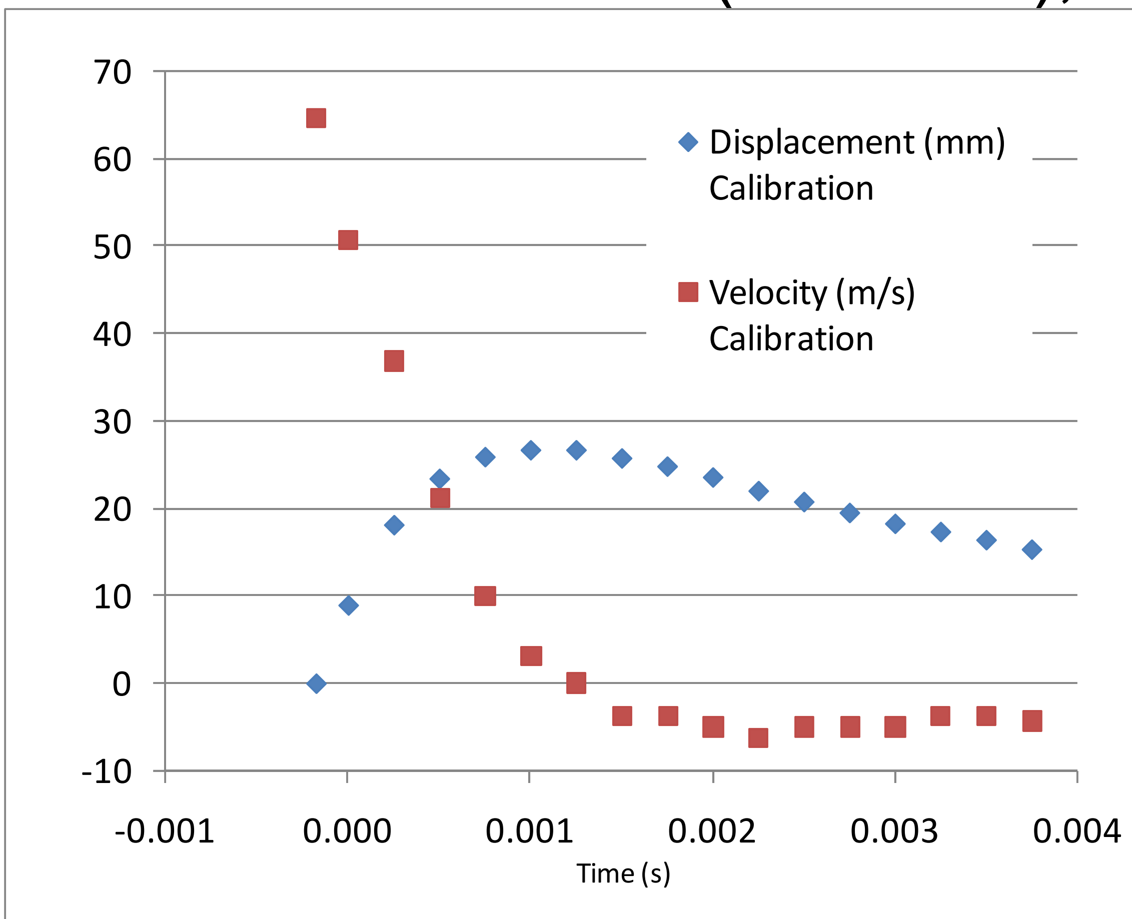


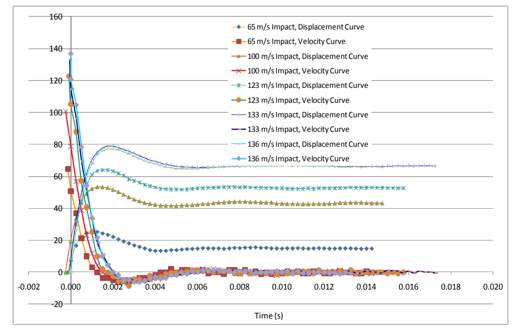


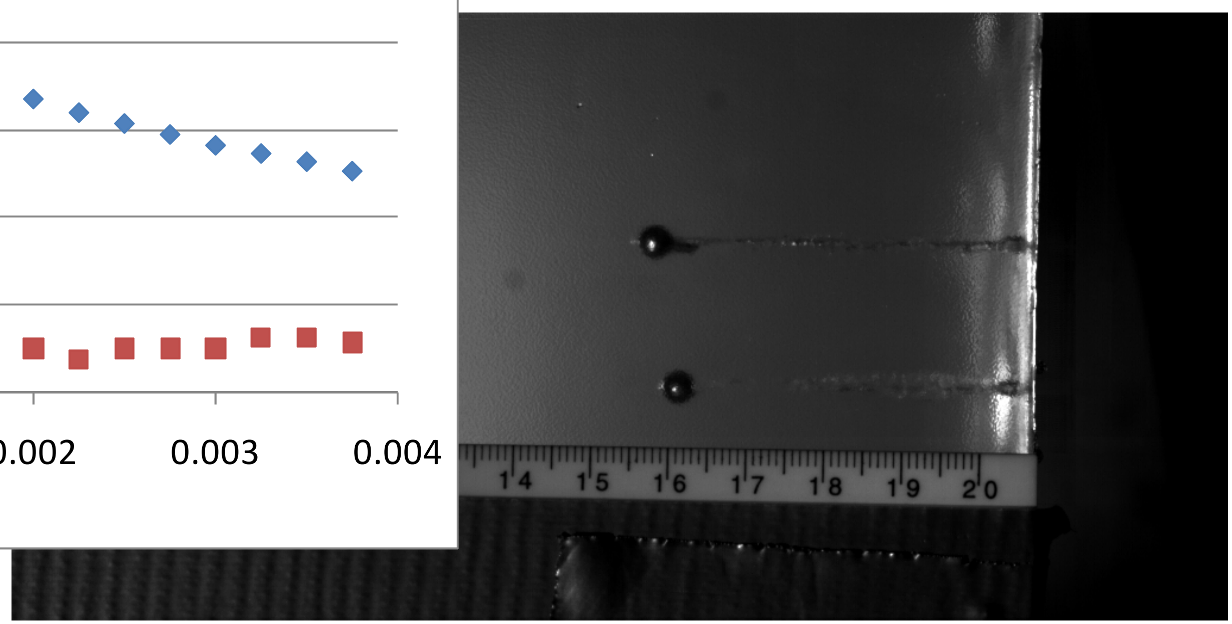


Results – Gelatin Calibration

- Calibration test (10%/4°C), 65 m/s Impact

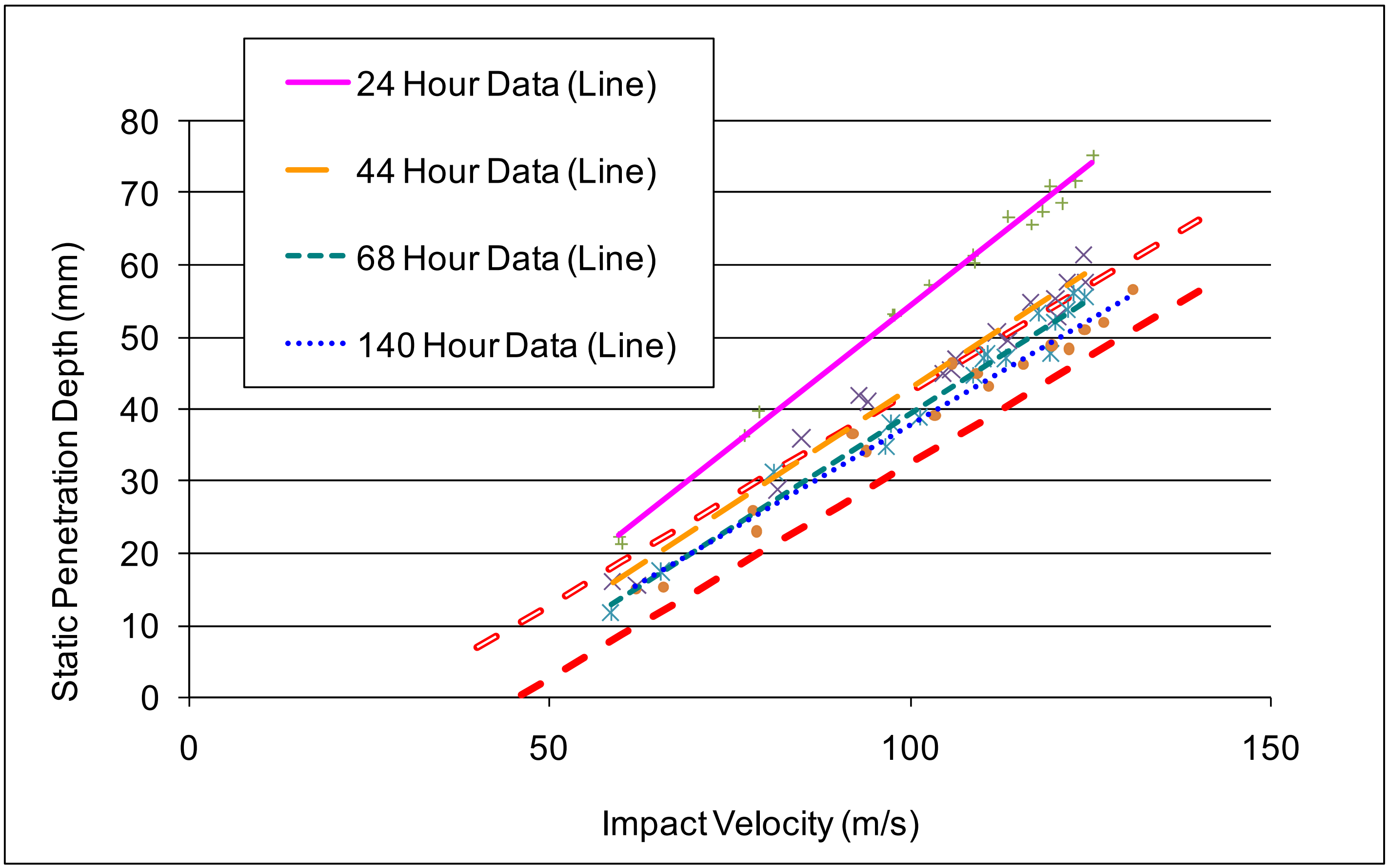






Results – Gelatin Calibration

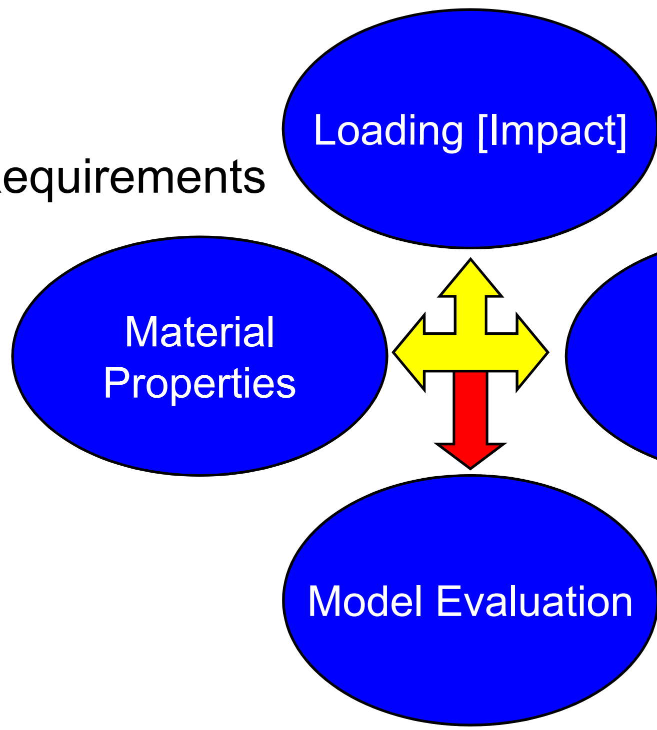
- Calibration tests at various impact velocities (10%/4°C)
  - Significant dependence on aging / conditioning time
  - Linear relationship (r^2 = 0.97 to 0.99)

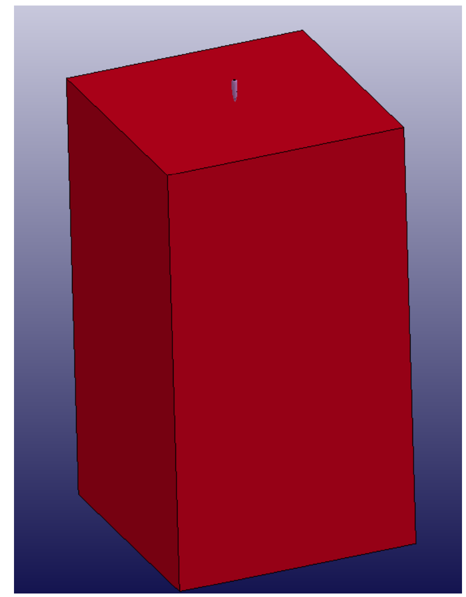


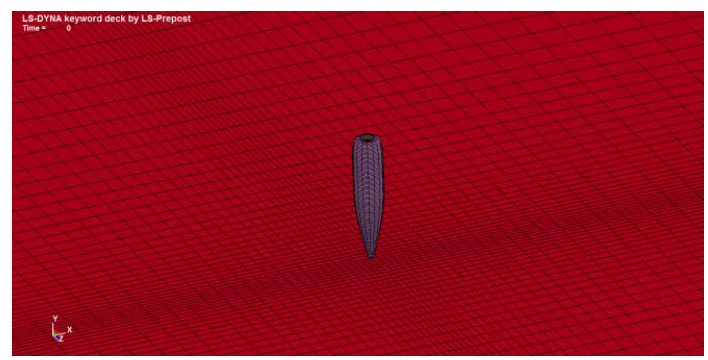
Impact modeling

- Explicit FE (LS-Dyna v971) w/ LSOPT
- High strain rate material properties w/ damage/failure
- Lagrangian, ALE, EFG formulations

Model Requirements

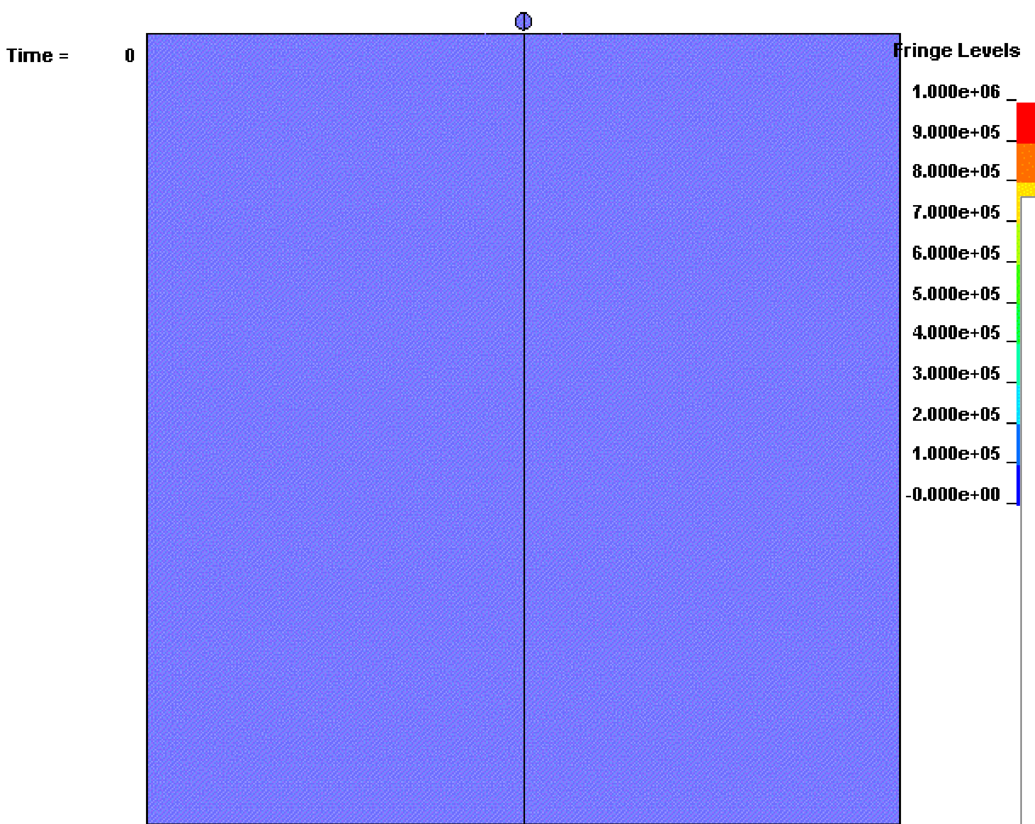


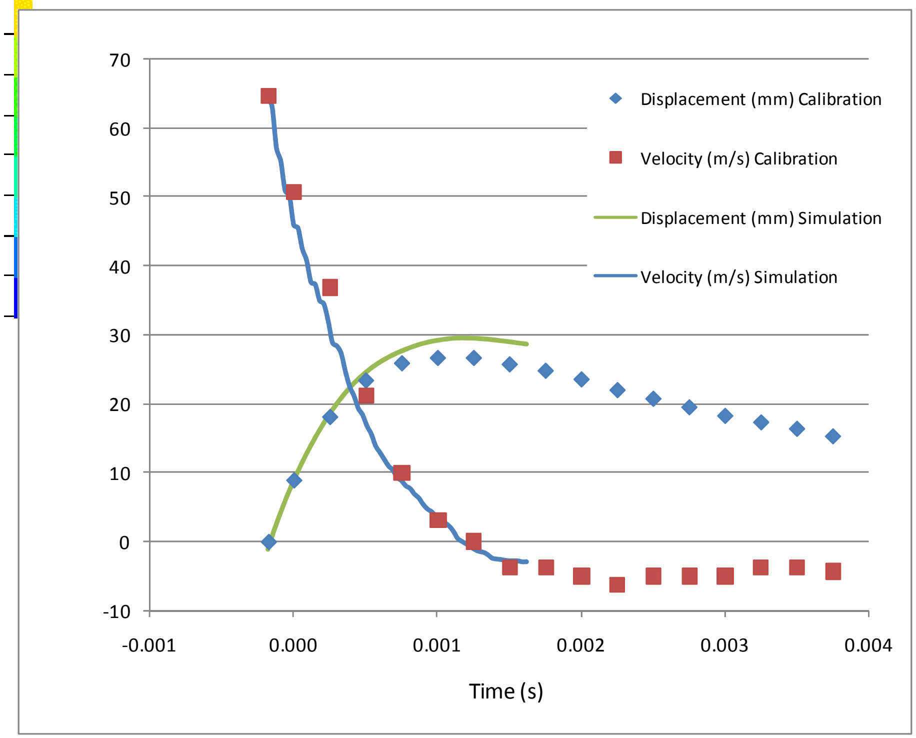




Impact modeling – Phase 1

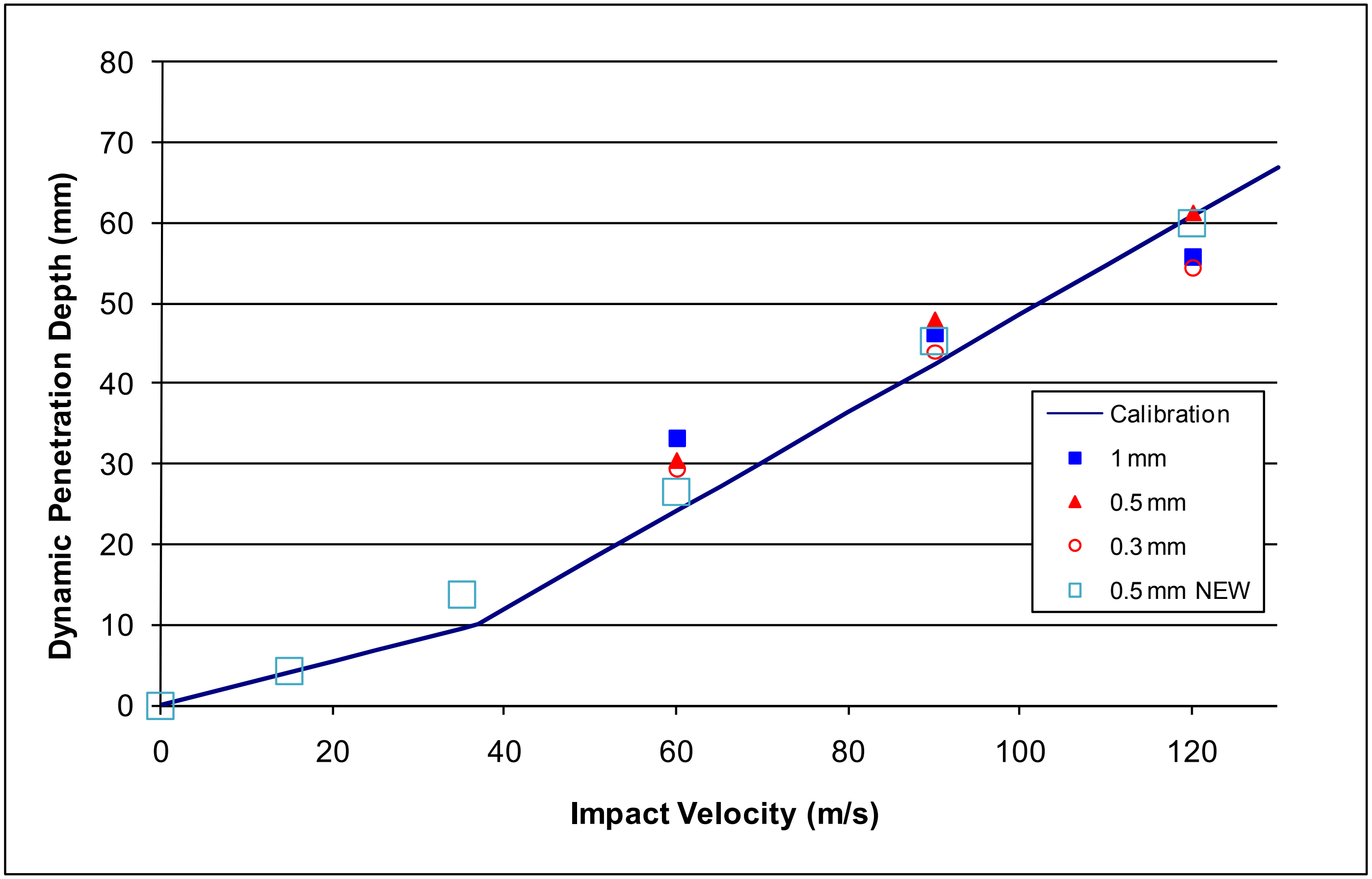
- BB impact model
  - 65 m/s BB impact on gelatin block (10%/4°C)





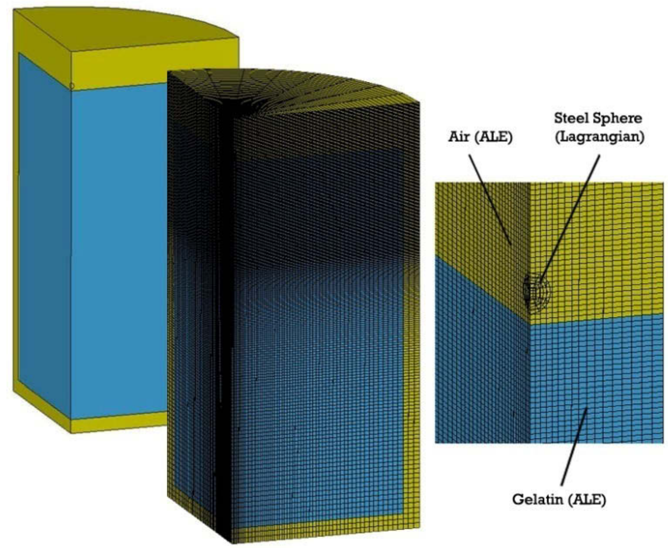
Impact modeling

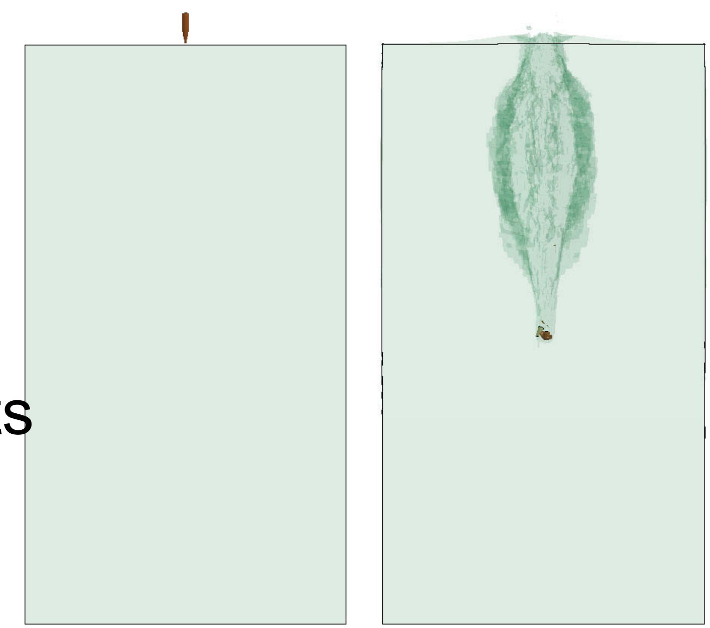
- Generally in good agreement with experiments
- Mesh size dependency



Impact modeling – Phase 2, 3

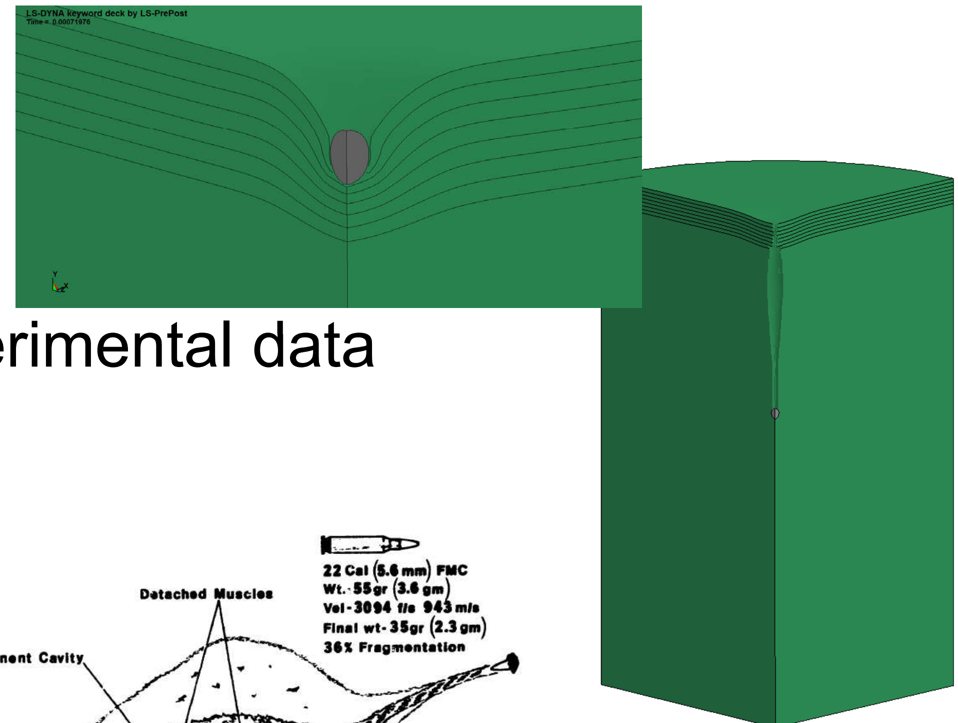
- 3-D Lagrangian model
- 3-D ALE model
  - Large deformation
  - Material 'self healing'
  - Limited material models
- 3-D EFG model
  - Large deformation
  - Significant compute requirements



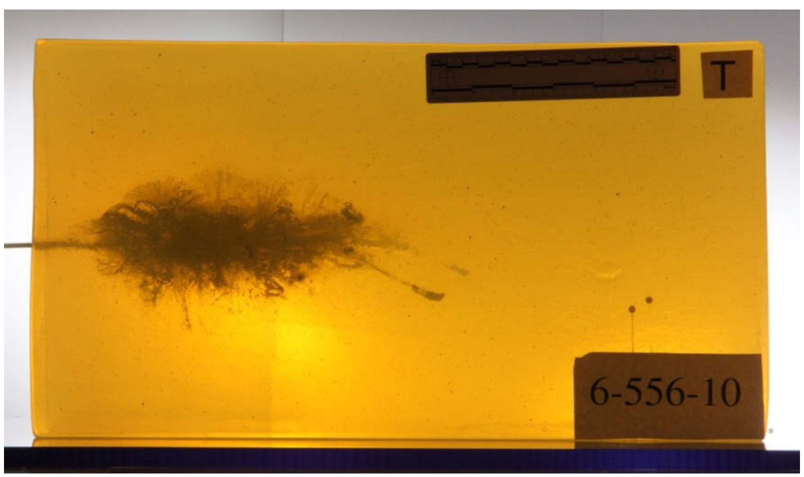


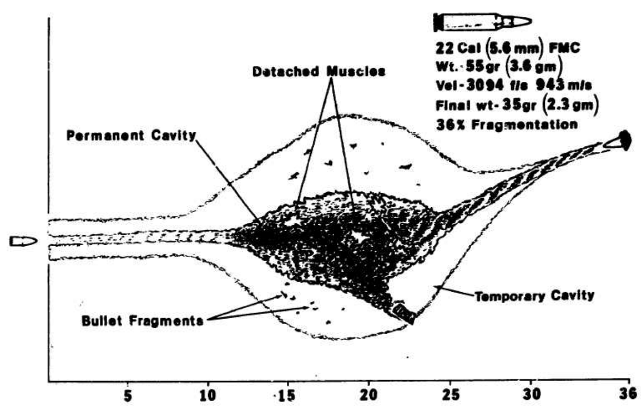
Impact modeling – Phase 3

- 3-D Lagrangian model
  - BB impact simulations



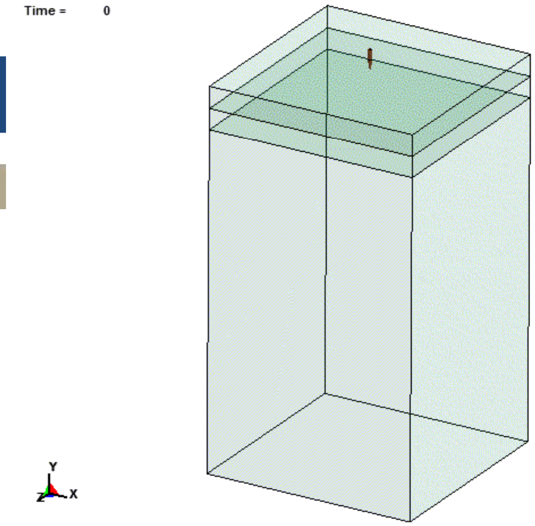
  - Projectile impact – experimental data

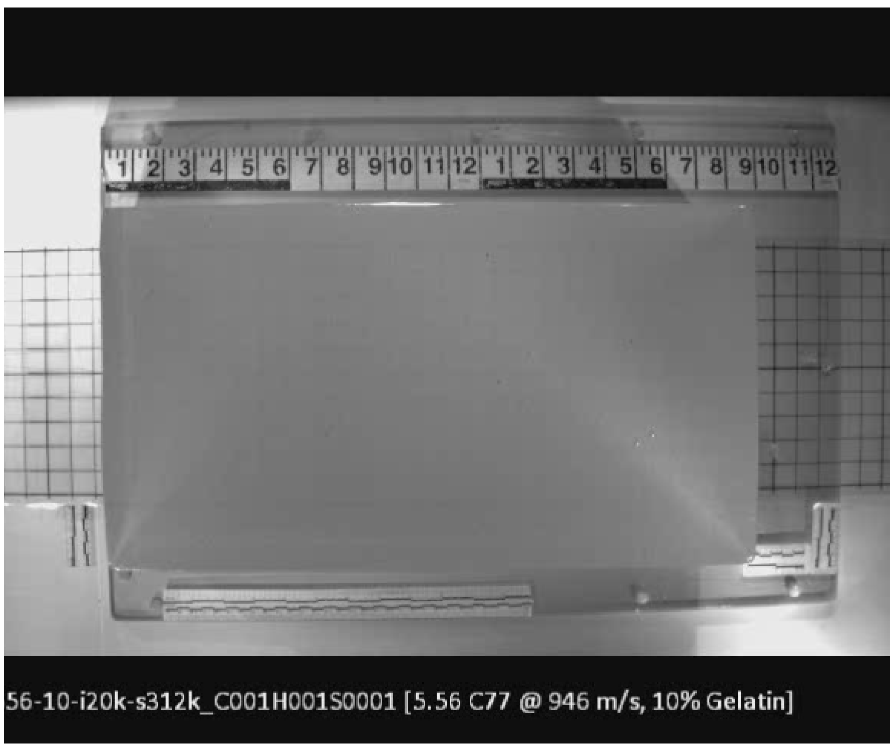


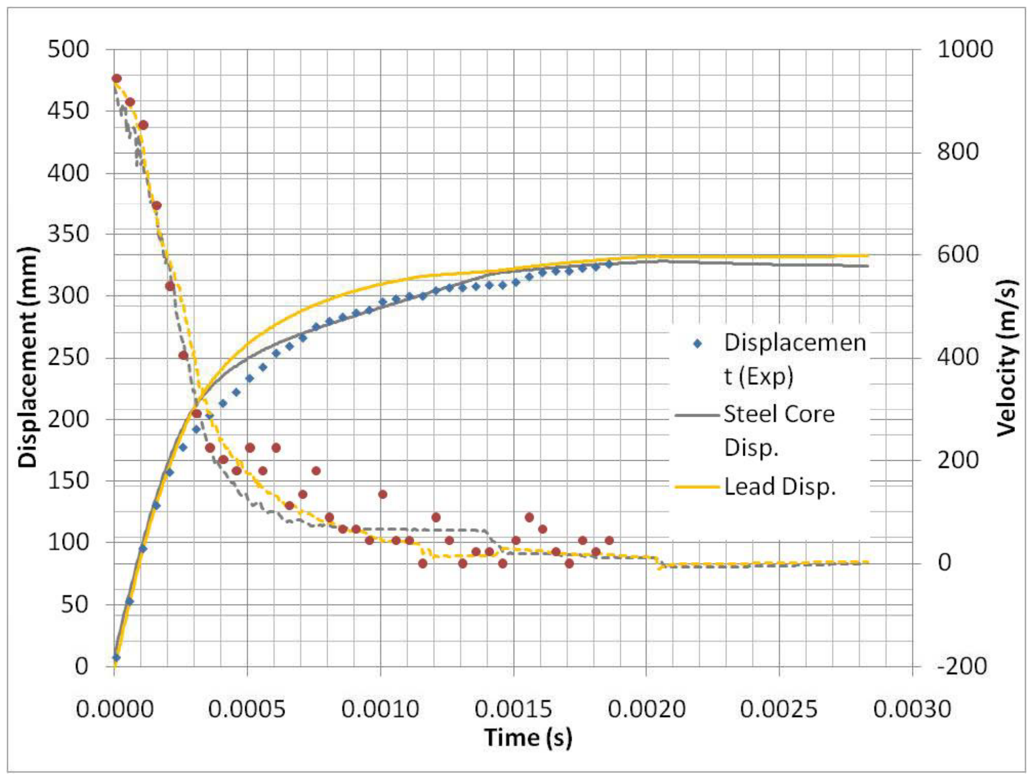


Impact modeling – PI

- 3-D Lagrangian model
  - Projectile impact







Conclusions

- Mechanical characterization (10% / 4°C gelatin, 0.01 s^{-1} up to ≈1500 s^{-1})
  - Integration in constitutive model with damage
- Modeling of calibration test impact (BB)
  - Threshold velocity important
- 3-D Projectile impact models
  - ALE
    - Limited by available material properties
  - EFG
    - Promising for large deformations, but computationally expensive
  - Lagrangian
    - Good agreement with experimental data
    - Computationally efficient